

**EXPERIMENTAL STATUS DVCS $ep \rightarrow ep\gamma$
AND $en \rightarrow en\gamma$ AT JEFFERSON LAB-HALL A**

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The experiments E00-110 and E03-106 [1] propose to measure the Deep Virtual Compton Scattering process (DVCS) $ep \rightarrow ep\gamma$ and $en \rightarrow en\gamma$ in Hall A at Jefferson Lab with a 5.75 GeV longitudinally polarized electron beam. The exclusivity requires the High Resolution Spectrometer of the Hall A for the detection of the scattered electron ($\Delta p/p = 10^{-4}$), an electromagnetic calorimeter for the detection of the real photon ($\sigma/E < 5\%$) and a scintillator array for the detection of the third particle. A 1 GHz sampling system allows one to deal with pile-up as expected from running detectors at small angles and high luminosity $\mathcal{L} = 10^{37} \text{ cm}^{-2} \text{ s}^{-1}$. We will describe the apparatus and will explain the method to extract GPDs and evaluate the contributions from higher twists from the measurement of the cross-section difference.

1. Introduction

The Generalized Parton Distributions (GPDs) framework introduced seven years ago allows one to have a unified description of the nucleon, including form factors and structure functions, but also including two-parton correlations and transverse momentum dependence [2, 3]. The QCD factorization theorems [4] have established that GPDs can be measured via exclusive reactions in the so called deeply virtual limit (fixed Bjorken variable x_B , $Q^2 \gg \Lambda_{QCD}^2$, $Q^2 \gg -t$, $t = (p' - p)^2$, p and p' initial and recoil nucleon four-vectors). The simplest exclusive process that can be described in terms of GPDs is Deeply Virtual Compton Scattering (DVCS) $\gamma^* N \rightarrow \gamma N$, measured in the exclusive electroproduction reaction $eN \rightarrow eN\gamma$ in deep inelastic scattering kinematics (DIS). X. Ji [2] suggested using DVCS to get information about GPDs which generalize the concept of parton distributions found in DIS. The DVCS amplitude can be factorized in a soft part

containing the non-perturbative physics and described by the GPDs E , H , \tilde{E} and \tilde{H} and a parton process calculable via perturbative QCD [3, 4].

2. GPD's measurement

The exclusive electroproduction $eN \rightarrow eN\gamma$ involves two processes. The real photon of the final state can come from the DVCS process or can be radiated by the lepton from the Bethe Heitler (BH) process. The BH process is completely calculable at small t . The interference between these two processes dominates the difference of cross-sections between longitudinally polarized electrons of opposite helicities and is proportional to the imaginary part of the DVCS amplitude intensified by the full magnitude of the BH amplitude. The helicity structure of DVCS gives rise to an angular dependence on the variable φ , the angle between the leptonic (e, e') plane and the hadronic (γ^*, γ) plane. The specific observable we propose to measure is this cross-section difference as a function of φ [5] which is non-zero only if the emitted photon is out of the electron scattering plane ($\varphi \neq 0$). Its full expression is given by [6]:

$$\frac{d\vec{\sigma}}{dx_B dy dt d\varphi} - \frac{d\overleftarrow{\sigma}}{dx_B dy dt d\varphi} = \Gamma(x_B, y, t, \varphi)(A \sin \varphi + B \sin 2\varphi) \quad (1)$$

where $\Gamma(x_B, y, t, \varphi)^a$ is a kinematical factor from BH propagators.

The experiments will provide the first checks of the Q^2 -dependent scaling of the DVCS amplitude, as well as an evaluation of linear combination of the GPDs (A coefficient) and study the higher-twist effects (B coefficient). We plan to measure the helicity dependent cross-section for three kinematics using a 5.75 GeV beam, ranging from $Q^2 = 1.5$ to 2.3 GeV^2 at fixed $x_B \sim 0.35$ (expected result on Figure 1) in order to study the Q^2 dependence of A and B . At leading twist, this asymmetry reduces to the $\sin \varphi$ term for which the coefficient is directly linked to the GPDs H, E and \tilde{H} :

$$A = F_1(t).H + \frac{x_B}{2-x_B}(F_1(t) + F_2(t)).\tilde{H} - \frac{t}{4M^2}F_2(t).E \quad (2)$$

where $F_1(t)$ and $F_2(t)$ are the Dirac and Pauli form factors. In the proton case, the leading term is $F_1(t).H$. Indeed, $F_1(t)$ and H are large for the proton, unlike $F_2(t)$, \tilde{H} and E which turn out to be much smaller. In the neutron case, the $F_1(t)$ form factor is much smaller than $F_2(t)$, unlike in the proton's case. Then the leading term becomes $-\frac{t}{4M^2}F_2(t).E$ since \tilde{H} is small. The neutron DVCS experiment is complementary to the proton's.

^a $y = \frac{k-k'}{k}$, where (k, k') energies (e, e')

With both experiments, one will have the first accurate handle on the two GPDs H and E , the latter being basically unknown and unconstrained. The cross-section difference can be directly related to GPDs but its measurement is more difficult than trying to access the single spin asymmetry where the detectors efficiency cancels out.

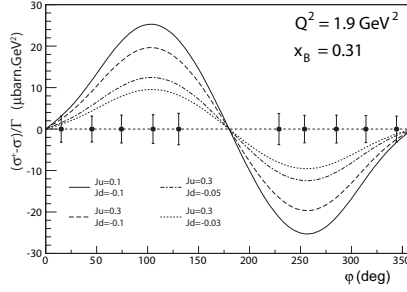


Figure 1. Expected result for the weighted cross-section difference in 300 hours of beam time at $\mathcal{L} = 4.10^{37} \text{cm}^{-2} \text{s}^{-1} \text{nucleon}^{-1}$ (LD2 target). The curves are prediction from a model [7] for different values of the parameters J_u and J_d , fractions of angular momentum carried by the u and d quarks in the proton.

3. Experimental setup

A longitudinally polarized electron beam will be used, along with the 15 cm Hall A, hydrogen or deuterium, cryotarget. The Hall A electron spectrometer will be used to detect the scattered electrons with a high resolution $\Delta p/p = 10^{-4}$. The scattered photon will be measured by an electromagnetic calorimeter. It consists of 132 blocks of lead fluoride, each with dimension 30 mm x 30 mm x 184 mm. Lead fluoride is very dense ($\rho = 7.66 \text{ g/cm}^3$), with a short radiation length ($X_0 = 0.95 \text{ cm}$) and a small Moliere radius ($r_M = 2.22 \text{ cm}$), which allows to build a compact calorimeter. The calorimeter will be centered along the direction of the virtual photon and placed 110 cm from the target. The resolution, σ/E , is less than 5% for 3 GeV DVCS photons energy. In order to ensure the exclusivity of the reaction, the third particle is detected.

In the proton DVCS case, the recoil protons will be detected in a 100-element plastic scintillator array. This array is matched to the out-of-plane acceptance ($\varphi \neq 0$) required to measure the beam helicity asymmetry in deeply virtual kinematics. The array subtends polar angles 18° to 38° in five rings around the direction of the virtual photon. Each ring is divided

into 20 elements that together subtend azimuthal angles from 45° to 315° (gap for exit beam pipe).

In the neutron DVCS case, the neutron detection and the proton/neutron discrimination will be achieved by adding iron shielding and a charged particle tagger in front of the scintillator array. The tagger system consists of 2 overlapping layers of 2 cm-thick scintillator paddles placed in front of each block of the scintillator array, allowing to identify charged particles with a very high efficiency while having a low efficiency to neutral particles. The ring of segmented scintillators (blocks and paddles) is located about 70 cm from the target (Figure 2).

Each block of the calorimeter and each scintillator is coupled to a photomultiplier. Due to the proximity of the detectors from the target and the beam pipe, high singles rate \sim MHz are expected. This induces pile-up and limits the accepted luminosity. To cope with this, the calorimeter and scintillator array/paddles information are recorded using a novel system: Analog Ring Samplers. Each channel of the detectors is continuously sampled and stored on a 128-capacitor ring at a frequency of 1 GHz. The sampling allows to perform a shape analysis and subtract the pile-up events from the DVCS events. Solving this pile-up problem enables to reach a higher luminosity and perform the experiment on a reasonable time scale.

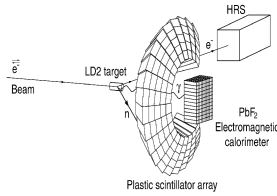


Figure 2. Schematic of the neutron DVCS setup.

4. Physics analysis

The aim is to extract the values of the A and B coefficients which appear in the difference of cross-sections for opposite helicities:

$$\frac{d\vec{\sigma}}{dx_B dy dt d\varphi} - \frac{d\overleftarrow{\sigma}}{dx_B dy dt d\varphi} = \Gamma(x_B, y, t, \varphi)(A \sin \varphi + B \sin 2\varphi) \quad (1)$$

The $\sin \varphi$ coefficient has no Q^2 dependence and the $\sin 2\varphi$ is expected to have $1/Q$ dependence. The difference between the number of counts binned

in φ and t for opposite helicities $\vec{N}(\Delta\varphi_i, \Delta t_j) - \overleftarrow{N}(\Delta\varphi_i, \Delta t_j)$ corresponds to the cross-section difference convoluted by the experimental efficiency:

$$\begin{aligned}\vec{N} - \overleftarrow{N} &= \mathcal{L}.A(\bar{x}_B, \bar{t}).\mathcal{I}_1(\Delta\varphi_i, \Delta t_j) + \mathcal{L}.B(\bar{x}_B, \bar{t}, \bar{Q}^2).\mathcal{I}_2(\Delta\varphi_i, \Delta t_j) \\ \mathcal{I}_1(\Delta\varphi_i, \Delta t_j) &= \int_{\Delta\varphi_i, \Delta t_j} \sin\varphi.\Gamma(x_B, y, t, \varphi).\varepsilon_{ff}(x_B, y, t, \varphi)dx_B dy dt d\varphi \\ \mathcal{I}_2(\Delta\varphi_i, \Delta t_j) &= \int_{\Delta\varphi_i, \Delta t_j} \sin 2\varphi.\Gamma(x_B, y, t, \varphi).\varepsilon_{ff}(x_B, y, t, \varphi)dx_B dy dt d\varphi\end{aligned}$$

- $N(\Delta\varphi_i, \Delta t_j)$ collected counts in the bin (i, j) in (φ, t) ,
- $\varepsilon_{ff}(x_B, y, t, \varphi)$ detectors efficiency and \mathcal{L} the luminosity,
- $\mathcal{I}_1(\Delta\varphi_i, \Delta t_j)$ and $\mathcal{I}_2(\Delta\varphi_i, \Delta t_j)$ computed from Monte Carlo.

For each bin in the variable t , a system of linear equations (one for each φ bin) is built from which the A and B coefficients are extracted.

5. Conclusion

The GPDs have just been tackled by recent measurements which have confirmed that DVCS experiments can be achieved at existing facilities and especially Jefferson Lab at moderate Q^2 [8]. The first dedicated experiment in Hall A will extract the helicity dependent DVCS cross-sections on the proton in the Q^2 range 1.5-2.3 GeV². However, proton experiment can only constrain or extract the H and \tilde{H} GPDs. A neutron DVCS experiment will be mostly sensitive to the least known of GPDs: E , essential for the understanding of the nucleon structure and to access the total angular momentum carried by the quarks in the nucleon from X.Ji's sum rule [2].

References

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